Taking Account of Non-Timber Values in Harvest Decisions in the Southern Forest of Tasmania

Campbell, H. F. and Jennings, S.M. (2004), *Taking Account of Non-Timber Values in Harvest Decisions in the Southern Forest of Tasmani*a, Discussion Paper No 332, School of Economics, The University of Queensland.

Abstract

This paper examines the optimal use of a site containing standing timber, taking account of both timber and non-timber values. It discusses the range of non-timber values yielded by a typical site in the southern forest of Tasmania. Taking that site for illustrative purposes, it calculates the relationships between age of stand, extent of timber and non-timber values, and optimal cutting age, using a spreadsheet model. It finds that for a stand with moderate potential environmental benefits there is a period of its life during which it is optimal to log. This segment narrows, and eventually disappears, as potential environmental benefits increase.

Keywords: forest; timber; environmental benefits; optimal rotation

The authors are faculty members at The University of Queensland and The University of Tasmania respectively. They would like to thank officers of the Forestry Commission, Tasmania for providing data and useful comments, and anonymous referees for editorial suggestions. The authors are solely responsible for any errors or omissions and for the conclusions of the paper.

1. INTRODUCTION

The issue addressed in this paper is whether the value of an area of forested land is maximized by harvesting the timber according to some cutting cycle or by never cutting the trees. The standing forest will yield various types of non-timber values (see Calish, Fight and Teeguarden (1978) for a detailed description) as well as timber values if the current and future stands are harvested; alternatively, it will yield non-timber values if the forest is never harvested. The relevant comparison is between the timber values plus the non-timber values which would be generated as a by-product of forestry, and the non-timber values which would be generated through conservation.

The timber values of a tract of forest land are maximized by following an optimal rotation – a cycle of cutting that maximizes the net present value of the timber obtained from the land in perpetuity. Hartman (1976) and Swallow, Parks and Wear (1990) have described how the optimal rotation problem can be modified to include both the timber and non-timber values to be generated by a bare site. However, as noted by Bowes and Krutilla (1989), management for old-growth forest non-timber values would generally not be justified starting from a bare site because of the time required for old-growth to develop. In fact the case for conservation is usually driven by the non-timber values generated by the standing forest. Strang (1983) considers the optimal harvest decision when the standing forest has value as a stock of timber but also yields a current flow of non-timber benefits This more general problem yields a variety of solutions depending on the timber growth function and the timber and non-timber values chosen for the model, and, crucially, depending upon the age of the current stand of trees. The various solutions fall into three categories: wait until the current stand reaches the optimal rotation age and then cut and follow the optimal rotation; cut the current stand immediately and then follow the optimal rotation; or never cut the stand.

The general model is applied to a typical stand of Stringybark (*Eucalyptus obliqua*) in the southern forest of Tasmania. Growth functions are combined with price and interest rate data in a spreadsheet framework to determine threshold values – dollar values of annual environmental benefits which would be required to justify delaying cutting or never cutting stands of trees of various ages.

2 NON-TIMBER VALUES IN THE SOUTHERN FORESTS

The empirical application of the optimal cutting model is to a stand of temperate *Eucalyptus obliqua* forest, which is the most widespread forest type in Tasmania. The focus is on the lowland wet *Eucalyptus obliqua* forests as represented in the Warra Long Term Ecological Reserve (LTER) site. The Warra LTER site is a 15,900 ha area which lies between the Huon and Weld Rivers about 60 km west south-west of Hobart in Southern Tasmania. Most of the reserve is forested, the main forest type being wet *Eucalyptus obliqua*. These forests typically have a tall dominant overstory of eucalyptus, and a dense understory of either broadleaved scrubs (wet sclerophyll forest) or rainforest tree species (mixed forest). In the absence of fire, the latter will become cool temperate rainforest within 200 – 300 years. All successional phases of this forest community are represented in the Warra LTER. Forest age structure in the Warra reflects the area's history of wildfire. While some stands are even-aged due to high fire intensity in the past, others reflect a history of relatively low fire intensity and consist of several age classes.

The purpose of establishing the Warra LTER site was to provide a long-term, multidisciplinary experimental research program as a basis for ecologically sustainable management in forests of this type. Logging began in the Warra in the early 1970's, and the reserve has a long history of data collection for forestry purposes dating back to the late 1960's. In addition, the western portion of the Warra site is in the World Heritage Area, and is managed for conservation values. The eastern portion is State Forest, managed by Forestry Tasmania for a multiplicity of uses including wood production.

The past decade has seen substantial developments in both our appreciation of the range of outputs produced by forests and in our recognition of the need to integrate the value of these outputs into economic analysis of the use of forest resources. For example, the value of foregone recreation opportunities is now an acknowledged cost of harvesting oldgrowth forests, while the potential revenue from the sale of carbon credits is often included as a benefit of plantation establishment. These developments have mirrored advances in our knowledge of the complex and uncertain interactions which exist between the natural world and the economy, and our recognition of the importance of the natural world for sustaining human life on earth and for a range of non-market and non-use values for human fulfilment.

Wills (1999) lists four main functions of the natural world, all of which may be impaired through the operation of our economic system. First, the natural world is a source of inputs to the production process, whereby the technological and entrepreneurial ingenuity of mankind is harnessed to convert inputs into valued (if not useful) products and services. Secondly, the natural world plays a role as a waste sink, whereby potentially harmful by-products of consumption and production are rendered benign through natural assimilative processes. Thirdly, the natural world can be the direct source of amenity or pleasure *in situ*. Finally, by maintaining the flow of energy and the cycling of chemical elements, the complex network of living organisms and non-living materials, provide our life support system. Forests produce outputs that contribute to each of these functions. The raw materials for housing, paper and many pharmaceutical products come from forests, and in many parts of the world wood is an important source of fuel. From a human perspective, trees have a beneficial effect on the atmosphere by absorbing carbon and releasing oxygen. Forests also contribute directly to our enjoyment by providing a place to walk in solitude or to ride our mountain bikes, habitat for wildlife or as a pleasing view.

While there is no universally recognized taxonomy of the values associated with natural and environmental assets, economists generally distinguish between use and non-use value. Use value may be direct, in the sense that an individual must come into direct contact with the resource in order to benefit, or indirect, in the sense that the value of a resource may be derived without contact. For example, a type of indirect use value is assigned when an individual buys a Tasmanian Wilderness calendar or benefits from the results of research on flora or fauna which rely upon unmodified ecosystems for their habitat.

Use value may be either consumptive or non-consumptive in nature. It is consumptive if use results in the depletion of the resource or otherwise impairs the resource’s ability to produce a sustained flow of services. Non-consumptive uses are enjoyed without altering the nature or availability of the resource. For example, viewing scenery, photography and non-congestive recreation are non-consumptive uses.

Not all values involve active use of the resource. In fact, individuals may assign value to resources that they have no intention of ever using. This possibility implies that basing estimates of total value on the values assigned by the population of current users will underestimate benefits. Adamowicz *et al*. (1991) referred to assigned values in these circumstances as preservation value. Preservation value consists of two major components, namely existence and bequest value.

As the name suggests, existence value results when an individual gains satisfaction in the knowledge that a resource exists. For example, there are many individuals who have never seen, nor will ever see Tasmania's wilderness resource. Nevertheless, they would experience a real loss if the wilderness qualities of the area were destroyed. So long as these qualities are preserved, the resource is assigned a value. Existence values can be further classified into those motivated by altruistic and those by intrinsic held value. Existence values which stem from the intrinsic motive are called pure existence values and are perhaps most easily identified with environmental ethic. Pure existence value may, for example, stem from a belief about how the world should be ordered or a sense of "natural" justice. Actions which result in consequences which violate this sense of environmental "right" and "wrong" will result in people being worse off. Existence value can also be motivated by altruism in the sense that pleasure is derived from knowing that others are made better off by some action or decision. For example, a person might be willing-to-pay a positive sum to ensure that a friend is able to enjoy a direct recreational wilderness experience. This type of existence value was referred to by Adamowicz *et al*. as vicarious consumption value. Bequest value is defined as the value individuals assign to the preservation of a resource so that their heirs will have the opportunity to benefit from the resource's availability. In a sense, then, bequest value is a special form of intergenerational vicarious consumption value.

The temperate wet *Eucalyptus obliqua* forests as represented in the Warra LTER not only provide a rich source of merchantable timber upon which a significant local and regional forest industry and its associated local communities have been built, but they also provide a wide range of non-timber outputs and ecosystem services. Table 1 provides a catalogue of these outputs and services, and for each indicates both the geographical scale and growth stage of the forest at which they occur. For example, the production of leatherwood honey and the provision of habitat for hollow-dependent biota such as owls occurs in the mature and old growth phases of the forest. On the other hand, the output of pioneering biota such as fireweed occurs in regenerating and regrowth stands. The quantity of water bears a u-shaped relationship with the growth stage of the forest, with highest level of water flow occurring in regenerating and old growth stands.

Table 1: Non-timber Forest Outputs and Ecological Services in temperate wet *Eucalyptus obliqua* Forests

Forest Output or Ecological Service	[2] **Scale of Supply**[a]	**Growth Stage**[b]	**Comment**
Special species timbers	Stand to region	m, o	Blackwood, celery top pine
Honey	Stand to region	m, o	Leatherwood
Seeds	Stand to region	Rth, m, o	Eucalypt
Horticultural material	Stand to region	All	Tree ferns
Sap/resin/oils*	Stand to subregion	All	Eucalypt, tea tree
Bark*	Stand to subregion	M, o	
Charcoal*	Stand to subregion	Rth, m, o	
Medicinal chemicals*	Stand to subregion	All	
Dried flowers/foliage	Stand to subregion	All	Myrtle sprays
Craft materials	Stand to region	M,o	
Dyes*	Stand landscape	All	
Bio fuels/energy*	Stand to region	Rth, m, o	
Eco tourism	Landscape to region	M, o	
Accommodation	Subregional	N/a	
Recreation	Landscape, subregion	N/a	
Species richness	Stand to global	All	
Species abundance	Stand to global	All	
Birds	Stand to global	All	
Birds sedentary Birds wide ranging Birds hollow dwelling	Stand to landscape Landscape to global All	All All m, o	
Invertebrates	Stand to global	All	
Angiosperms	Stand to global	All	
Conifers	Stand to region	o	NB: compare CTP with Huon pine
Ferns	Stand to region	All	NB late succession
Bryophytes	Stand to region	All	NB late succession
Lichens	Stand to region	All	NB late succession
Fungi	Stand to region	All	
Algae	Stand to region	All	
Mammals	All	All	
Amphibians	All	All	
Fish	All	All	
Biota hollow dependent	Stand to region	m, o	Owls
Biota pioneering	Stand to region	Rn, rth	Fireweeds
Biota decomposers	Stand to region	All	Amphipods
Epiphytes	Stand to region	m, o	Filmy ferns
Ephemerals	Stand to region	All	Orchids
Pollinators	Stand to region	All	Honey eaters
Eutrophic system indicators	Landscape to subregion	N/a	Nitella
Clean water indicators	Stand to sub region	N/a	Turbidity
Water quality	Stand to subregion	N/a	Macro inverts (crayfish)
Water quantity	Stand to sub region	Rn, o	U-shape change with age
Clean air	Stand to global	N/a	
Insectivores	Stand to region	N/a	Ladybirds, echidna
Genes – disease resistance, frost tolerance etc*	Stand to global	m,o	
Biological control predators	Stand to global	All	Lady birds
Soil quality	Stand to landscape	All	
Aesthetics	Stand to subregion	(rth), m, o	
‘old growth’	Stand to landscape	o	
Virgin/primary forest	Stand to landscape	All	
Fern glades	Stand	M, o	
Riparian picnic areas	Stand to landscape	N/a	

Camping	Stand to landscape	Rth, m, o	
Rafting	Landscape	N/a	
Bushwalking	Landscape	Rth, m, o	
Bird observing	Stand to landscape	Rth, m, o	
Plant hunting	Stand to landscape	All	
Insect hunting	Stand to landscape	All	Beetles
Food gathering*	Stand to landscape	(all)	
Mountain climbing	Landscape	N/a	
Rock climbing	Landscape	N/a	
Hunting	Landscape	All	
Wilderness enjoyment	Stand to landscape	M,o	
Spiritual values	Stand to landscape	(rn,rth) m, o	
Human habitation*	Stand to landscape	Rth, m, o	2ha farms etc
Natural laboratory	Stand to global	All	Scientists, field naturalists
Carbon	All	All	

a Stand level (coupe, SST); landscape (Warra); sub region (Huon); region (Tas); National? Global
b Less than 20 years old (regeneration):rn; 20 –85 years old (regrowth):rth; 85 – 200 years old (mature):m; and greater than 200 years old (oldgrowth):o.
* not commercial at present, or not represented in Warra.

Source: Mick Brown and John Hickey, Forestry Tasmania

3. OPTIMAL CUTTING AGE FOR TIMBER VALUE

The value of standing timber on a tract of forest land is termed the stumpage value, and is given by:

$$S(t) = p(t)x(t) - c \qquad (1)$$

where $p(t)$ is the average price per cubic metre obtained for the harvested timber, $x(t)$ is the volume of timber in cubic metres (assumed to be an increasing function of time), and c is the harvesting cost of the tract. The net present value of the timber which can be obtained from a bare tract of forest land by following repeated cutting rotations of length t is given by:

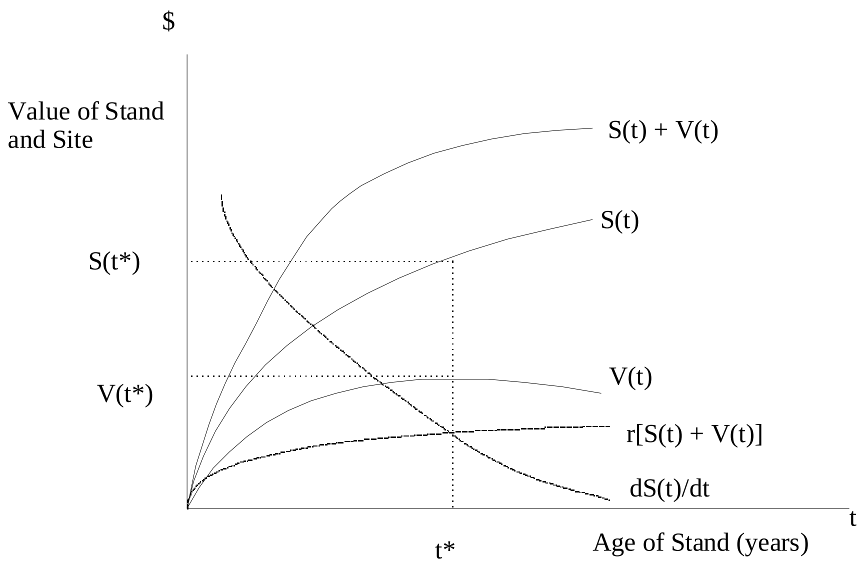
$$V(t) = S(t)/[(1+r)^t - 1] \qquad (2)$$

where r is the rate of interest. The value of t, t*, which maximizes V(t) is termed the optimal rotation, and is the solution to:

$$dS/dt - r(S(t) + V(t)) = 0. \qquad (3)$$

The intuition underlying this equation is that as long as the growth in value of the stand, *dS/dt*, exceeds the opportunity cost of holding the stand, which is the foregone interest on the value of the standing timber, *S(t)*, plus the value of the site, *V(t)*, it pays to allow the stand to continue to grow. Since growth in value is a decreasing function of time there comes a point at which the opportunity cost of holding the stand exceeds growth in value and the stand is cut and replanted or allowed to regenerate.

Figure 1: Calculating the optimal rotation taking account of timber value only



The calculation of the rotation age which maximizes the present value (NPV) of timber which can be obtained from a site supporting a stand of trees of age t is illustrated in Figure 1. The site value, *V(t)*, is maximized at rotation age *t**. The net present value of the stand plus the site, on a rotation age of t years, is given by *V(t) + S(t)*, which is an increasing function of time. The opportunity cost of continuing to hold the site plus stand is represented by *r[V(t) + S(t)]*, while the marginal benefit is *dS/dt*; this is the graphical representation of the solution to the optimal rotation problem.

In summary, the net present value of the timber which can be obtained from a tract of forested land supporting a stand of trees of age *t* is:

$$NPV(t) = \begin{cases} [S(t^*) + V(t^*)](1+r)^{-(t^*-t)} & \text{if } t \le t^* \\ [S(t) + V(t^*)] & \text{if } t > t^* \end{cases} \quad (4)$$

The rationale for this expression is that if $t \leq t^*$ the current stand should be allowed to grow to t^* before it is cut, and the tract then managed according to the optimal rotation; and if $t > t^*$ the current stand should be cut immediately, with the tract then being managed according to the optimal rotation.

As discussed in Section 2 above, there are many and varied non-timber benefits provided by the standing forest. While most of these benefits are in the nature of public goods and do not attract a price in the market economy, they may nevertheless confer significant benefits on the community. There exist a variety of methods for placing dollar values on these benefits, values that can be compared with the values generated by marketed goods such as timber. The non-timber benefits generated by the forest can be thought of as an annual flow of services, the value of which is related to the age of the stand or to the volume of timber it contains. Since volume depends on age we can express the value of this flow in either case as $F(t)$, where t is the age of the stand of trees.

There is no general agreement as to the exact form of $F(t)$ because of the variety of non-timber benefits produced by the forest and the difficulty of assigning dollar values to them. Hartman (1976) and Calish *et al.* (1978) take the view that the aggregate flow of non-timber values generated by the forest is likely to be an increasing function of the age of the stand. Swallow et al. (1990) suggest that the form of the $F(t)$ function will vary with the predominant type of non-timber benefit yielded by the stand, and that in some cases this will result in non-convexity of the forest net benefit function. Periods of time during which the growth rate of non-timber benefits exceeds the interest rate may give rise to multiple local maxima. Myopic policies based on current marginal conditions would result in the stand being harvested at the first age at which local first-order maximum conditions are satisfied. Strang (1983) emphasizes the need to consider boundary solutions, such as the never-cut option, as well as interior maxima. The spread-sheet approach adopted in the present paper is well suited to following Strang’s prescription as it allows us to inspect a wide range of possible solutions and choose a global maximum.

It is evident that non-timber benefits will be generated by land devoted to forestry as well as by land placed in environmental reserves. As explained by Hartman (1976), the optimal rotation calculation can be amended to take account of the annual value of the non-timber benefits generated as a by-product of forestry. In terms of Equation (3), the benefit of growing the trees for an extra period, dS/dt, is augmented by the value of the flow of environmental services over that period, and the site value of the land is augmented by the present value of the flow of environmental services which will result from all future rotations. The optimal rotation, t^{**}, now maximizes the present value of all future timber and non-timber values to be generated by the site. It will generally be longer than the rotation age which maximizes the present value of timber benefits only

The present value, at time t, of the non-timber benefits obtained from a stand aged $t<t^{**}$ and grown to age t^{**} is given by:

$$W(t,t^{**}) = \sum_{i=t}^{t^{**}} F(i)(1+r)^{-(i-t)} \tag{5}$$

When the value of non-timber benefits is added to the expression for the net present value of timber benefits to be obtained from a site supporting a stand of trees aged t, the expression for maximum NPV becomes:

$$\text{NPV}(t) = \begin{cases} W(t, t^{**}) + [S(t^{**}) + V(t^{**}) + R(t^{**})](1+r)^{-(t^{**}-t)} & \text{if } t \le t^{**} \\ [S(t) + V(t^{**}) + R(t^{**})] & \text{if } t>t^{**} \end{cases} \tag{6}$$

where t^{**} is the rotation age that maximizes the present value of timber plus non-timber benefits, $R(t^{**})$ is $W(0,t^{**})/[1-(1+r)^{-t^{**}}]$, which is the present value of the stream of environmental services to be generated by the site, and $S(t)$ and $V(t)$ represent timber values as before.

The net present value expression, $NPV(t)$, summarizes the net benefit of allocating a tract of land, with a stand of trees aged t years, to optimal forestry use, taking account of both timber and non-timber values. The question of whether the stand should be cut and managed on a rotation of length t^{**} to maximize the NPV of timber and non-timber benefits hinges on the relationship between $NPV(t)$ and the net present value of conserving (ie. never cutting) the stand. Assuming that the land is allocated to its highest value use, this comparison is relevant only for stands aged greater than t^{**} since the option of cutting will be exercised only when the stand is at least t^{**} years of age. If a tract of forested land is to be conserved because of the value of the non-timber benefits generated, the net present value of benefits is given by:

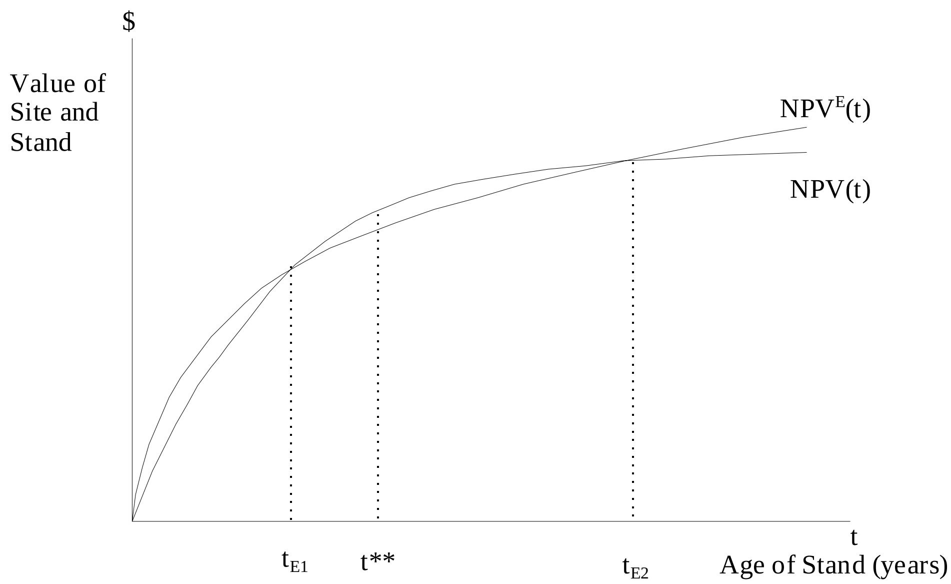
$$NPV^{E}(t) = \sum_{i=t}^{\infty} F(i)(1+r)^{-(i-t)} \tag{7}$$

which is an increasing function of *t*, the current age of the stand.

The efficient use of a tract of land supporting a stand of trees aged *t* years is in forestry as long as $NPV(t)>NPV^E(t)$, and as an environmental reserve as long as $NPV^E(t)>NPV(t)$. As noted by Strang (1983), and as will be seen in the empirical section of the paper, the type of use which has the higher net present value can change with the age of the current stand, denoted by *t*. For example, Strang notes circumstances in which, if *t* is less than some critical value, NPV is maximized by cutting at age *t* and following an optimal rotation thereafter, but if *t* exceeds the critical value NPV is maximized by never cutting the stand. It follows that a tract of forest land which is to remain an environmental reserve is one for which $NPV^E(t)>NPV(t)$ at the current and all future ages of the stand.

One possible outcome is illustrated in Figure 2. The $NPV(t)$ function cuts the $NPV^E(t)$ function at t_{E1} and t_{E2}, ages at which the present value of the stand as an environmental reserve equals its present value if managed to maximize the value of a combination of timber and non-timber values. For ages of the stand between t_{E1} and t_{E2} the value of the site plus standing timber is higher if the stand is cut than if it is conserved. The NPV is maximized by cutting at the optimal rotation t^{**} , but if the stand survives to age t_{E2} it should then optimally be conserved because of the environmental benefits generated by a mature age forest. Other

Figure 2: Net Present Value of the stand of trees in relation to stand age under optimal rotation and conservation management regimes



possibilities, not illustrated in Figure 2, are that the $NPV(t)$ function always lies above the $NPV^E(t)$ function, or intersects the $NPV^E(t)$ function only once at $t_{E1} < t^{**}$, in which cases it pays to cut the stand at any age $t > t^{**}$; or that $NPV(t)$ always lies below $NPV^E(t)$, in which case it never pays to cut the stand. In the case illustrated in Figure 2, the time interval between t^{**} and t_{E2} can be thought of as a window of vulnerability; stands in the age category $t^{**} < t < t_{E2}$ will optimally be logged. The window of vulnerability can shrink to zero, expand, or approach infinity, depending on the value attached to the flow of non-timber benefits yielded by the stand.

4. APPLICATION TO THE SOUTHERN FOREST OF TASMANIA

The approach outlined in Section 3 can be used to calculate what the value of the annual flow of environmental services yielded by a tract of forest land would have to be (the threshold value) to justify a decision never to cut the stand. The threshold approach has already been employed by Hartley (1995) in a study of the Eden Management Area. The tract chosen is a typical one hectare stand of eucalypt, predominantly Stringybark, in the southern forest of Tasmania.

Growth functions, developed from observations on single-aged research plots, were used to predict the entire stand volume (*ESV*) and the sawlog stand volume (*SLV*) for each age of the stand (Goodwin (1999)). Merchantable timber, consisting of sawlogs and pulp logs, is assumed to be 95% of *ESV* so that the volume of pulp produced is given by 95% of *ESV* less *SLV*. Stumpage value is calculated on the basis of sawlogs at $25 per cubic metre and pulp logs at $10 per cubic metre. These values are net of cutting, transportation and any site rehabilitation costs. A real interest rate of 3% is used to calculate present values.

The growth functions are:

$$ESV = \Delta_1 I \exp\left(-\alpha t^{-\beta}\right) \tag{8}$$

and

$$SLV = \Delta_2 I \exp\left[-\exp\left(-\gamma\left(t-\left(\phi+\frac{\varphi}{I}\right)\right)\right)\right] \qquad (9)$$

where t is the age of the stand, I is an index measuring the quality of the site and the Greek letters represent constants as reported in Table 2. Site quality is measured by the expected height of dominant trees at age 50 and for the purposes of the simulation was set at 26 which represents a fair to good site.

Table 2: Parameter Values used in the Stand Growth Simulation

$$\Delta_1 = 50; \alpha = 31.12; \beta = 0.8156; \Delta_2 = 13.217; \gamma = 0.0294; \phi = 10.43; \varphi = 2223; and\ I = 26$$

The growth functions are entered in a spreadsheet and evaluated over a 2000 year period. It should be noted that this length of time is obviously well beyond the range of the data used to generate the functions. To illustrate the behaviour of the growth functions, it can be noted that ESV assumes the logistic form, rising continually with age at a gradually decreasing rate after an inflection point at age 26 years: at age 100 years, for example, entire stand volume has risen to 628 m^3 with an annual growth of 3.7 m^3; by age 250 years ESV is 921 m^3, with annual growth of one cubic metre. SLV rises as a proportion of ESV until it reaches a maximum of 38% at 190 years of age; thereafter the proportion declines very gradually, to fall, for example, to 33% at 400 years of age, reflecting the decay of timber at advanced age. Some important factors which are ignored at this stage are the effects of fire, competition from rainforest species, and, in the case of a series of rotations, deterioration in site quality. In particular, eucalypts generally live up to 450 years and, unless regenerated, are replaced by a rainforest ecology. This means that expressing the annual environmental value as a function of the entire stand volume predicted by the growth model for a period in excess of 400-500 years is depends on the assumption that a fire event does not change the flow of non-timber benefits generated by the site. However, as will be seen below, most of the results are obtained from running the model for a period less than 400 years.

The dollar value of the annual flow of environmental services, *F(t)*, is assumed to be proportional to entire stand volume (*ESV*), where the factor of proportionality represents the annual environmental value in dollars per cubic metre of timber on the site:

$$F(t) = s.\ ESV(t). \qquad (10)$$

Since *ESV* is logistic *F(t)* also has the logistic form favoured by Hartman (1976) for the aggregate non-timber net benefit function. The value of *s* will be varied in the spreadsheet simulations to determine its threshold value – the minimum value it needs to take to justify never cutting the stand of trees.

5. RESULTS

The spreadsheet model indicates that the optimal rotation age when timber values alone are being considered is 32 years. This result is not very sensitive to small changes in the price of saw logs or pulp, but if the pulp value of the forest is disregarded optimal rotation ages rises to 94 years. However the main focus of interest is on the values of t**, when both timber and non-timber benefits are considered, and on the values of t_{E1} and t_{E2} as illustrated in Figure 2. As discussed earlier, the time interval t** to t_{E2} indicates the period of the stand’s life when maximizing the present value of the combined timber and non-timber values would indicate that it should be cut. We are interested in the size of this “window of vulnerability” in relation to the value of the parameter *s*. In particular we want to know the critical value of *s* at which the cutting window vanishes and the stand would optimally never be logged at any stage in its life.

The effect of increasing the value of the parameter *s* is to shift up the values of the *NPV(t)* and $NPV^E(t)$ functions in Figure 2, with the value of the $NPV^E(t)$ function rising by more than that of the *NPV(t)* function. The net result is a reduction in the size of the window of vulnerability. Some sample results are presented in Table 3.

Table 3: Optimal Management Regime in Relation to Environmental Value

Value of *s*	Ages at which the stand will be cut	
	r = 0.03	r = 0.031
0.0	32 onwards	31 onwards
0.1	37 onwards	37 onwards
0.2	50 onwards	48 onwards
0.3	86 onwards	83 onwards
0.4	109 onwards	107 onwards
0.5	138 – 1258	133 onwards
0.55	169 – 279	134 - 369
0.56	185 – 224	143 - 302
0.5633	never cut	157 - 247
0.5775	never cut	never cut

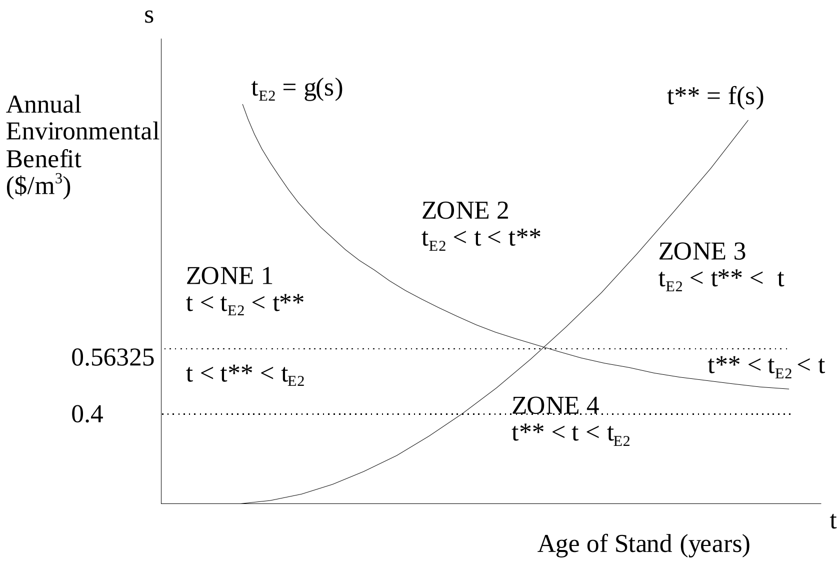
Note: *s* represents the annual environmental value in dollars per m^3 of entire stand volume and *r* is the real rate of interest

6. DISCUSSION OF RESULTS

It can be seen from the results presented in Table 3 that the window of vulnerability narrows sharply as the value of the parameter *s* increases; up to a value of s = 0.4 the size of the window tends to infinity, but as s increases from 0.5 to 0.563 the window is finite and shrinks rapidly to zero. From the viewpoint of the decision-maker this is unfortunate as very small changes in unit environmental value can significantly affect the optimal management regime. For example, if a stand aged in the range 185 - 224 years were being considered, a less than one cent per cubic metre increase in annual environmental value (from $0.56 to $0.563) would be enough to change the optimal regime from logging to never logging. The annual value of $0.56325 is the threshold value, which is the value of *s* at which the values of t** and t_{E2} in Figure 2 coincide: the *NPV(t)* function cuts the $NPV^E(t)$ function at t_{E1}, approaching it from below, and then at $t_{E2} = t^{**}$, approaching from above. To put the threshold value of *s* in perspective, when $s = 0.56325$, $t_{E1} = 185$ years, $t_{E2} = t^{**} = 195$ years, the annual value of the environmental services generated by the one hectare stand at age 195 years for that value of *s* is $480, the stumpage value is $12,981, the timber-only value of the stand plus site is $14,227, and the total value of the stand plus site is $16,770.

The results are illustrated in Figure 3. Both t^{**} and t_{E2} are drawn as functions of *s*, and the intersection point is the threshold value of *s*. The diagram can be divided into four zones depending on the relationship between the age of the stand, *t*, and the values of t^{**} and t_{E2}. In

Figure 3: Optimal cutting rule in relation to the environmental value of a stand of Eucalypt



zones 1-3 the optimal act is not to cut, either because the age of the stand is less than the optimal rotation (Zone 1), or because it is optimal never to cut (Zone 2), or because the stand has outgrown the age at which it should have been cut (Zone 3). Zone 4 represents the window of vulnerability – the range of stand age within which cutting is optimal. It can be seen that for lower values of *s* this range approaches infinity, whereas for higher values it narrow sharply towards zero as *s* rises towards the threshold value.

The spreadsheet evaluates three management regimes: (1) manage on a rotation that maximizes the NPV of timber values; (2) manage on a rotation that maximizes the NPV of timber and non-timber values; (3) conserve the stand in perpetuity. The social opportunity costs incurred as a result of choosing an inappropriate regime can be illustrated by considering the values, under each of the three regimes, of a one hectare stand of eucalypt aged 250 years for a range of *s* values. Under regime (1), irrespective of the value of *s*, the value of the site plus stand is $15,096, of which $13,850 is the value of the standing timber. Since the rotation age is 32 years any environmental values generated as a by-product of this management regime would be negligible. If s = 0.4 the rotation age that maximizes the present value of timber and non-timber benefits (t^{**}) is 110 years; under regime (2) the stand would be cut immediately and allowed to regenerate yielding a site plus stand value of

$16,609. Under regime (3) the site value is $12,668. If *s* = 0.6 the value of *t*** is 278 years and under regime (2) cutting the stand will be deferred for 28 years; the NPV of the site plus stand under this regime is $17,886. The NPV of adopting regime (3) is $19001. Thus for *s* = 0.4 choosing regime (1) has an opportunity cost of $1513 per hectare, and choosing regime (3) costs $3941. For *s* = 0.6 choosing regime (1) costs $3905, and choosing regime (2) costs $1115.

As noted earlier, the model was run for a period of time exceeding the natural life span of *Eucalyptus obliqua*, which is around 400-500 years, and it ignored the possibility of a stand-destroying fire. In the absence of fire the stand would gradually be replaced by rainforest species which would generate their own flow of non-timber benefits. If the value of that flow is similar to the very gradually increasing annual value imputed to the stand of eucalypt for ages in excess of 400 years, the relationship between the values of *s* and t_{E2} will still hold. Whether rainforest stands yield non-timber values similar to those of mature *Eucalyptus obliqua* stands is a question beyond the scope of this study.

The possibility of a stand-destroying fire is a more vexing issue. If it occurs during the natural life of the stand the forest will regenerate and, for all values of *s* at which there remains a window of vulnerability, it will eventually be logged. Whatever the fate of the tract of forest, its value has clearly fallen: it is worth less as a logging site; if fire changes its optimal use from preservation to logging, the latter is by definition a lower value; and even if it were to remain preserved, a generation of non-timber benefits related to mature stand volume has been lost. For any given value of the parameter *s*, introducing the probability of a stand destroying fire lowers the optimal rotation age, *t***, and raises the preservation age, t_{E2} , thereby widening the window of vulnerability. A crude way of modeling this effect is to add the annual probability of a stand-destroying fire to the rate of discount. If the annual probability were one tenth of one percent the stand would have around a 67 per cent chance of reaching maturity at age 400 years (a one per cent probability of fire would result in a 1.8 percent probability of reaching maturity).Adding 0.001 to the discount rate will widen the windows of vulnerability for various values of *s*, but make little difference to the threshold value: as can be seen from Table 3 the threshold value rises to *s* = 0.5775, which is associated with a t** (= t_{E2}) value of 191 years.

The model deals with a single stand of trees, whereas the concern of the forester is with managing the whole area of the forest. If timber values alone are considered it may be desirable to choose a cutting schedule that will eventually result in a normal forest – one with stand of each age-group of trees. If non-timber values are also considered, Bowes and Krutilla (1985) emphasize that the ecological interdependence of stands in providing amenity benefits must be taken into account. Swallow, Talukdar and Wear (1997) argue that ecological interdependence offers potential gains from specialization both spatially and temporally. The problem then is to draw the line between the forest that should be cut at some stage and the forest that should be permanently conserved.

Whether it is conceivable that stands of Stringybark in the southern forest could yield annual environmental benefits of the magnitudes required to support the conservation option is an empirical question. However the threshold value of $475 per hectare (in 2003 dollars) calculated in this study is comparable with the threshold value of $237 per hectare calculated by Hartley (1995) for the Eden Management Area. O'Shaughnessy and Jayasuriya (1991) calculated values of $1227 and $1472 respectively for the annual value of water production from 80 and 150 year old stands of Mountain Ash in the Tarago Catchment Area near Melbourne. Since their study values water at the price charged by the Melbourne Metropolitan Water Board, and their estimates are not threshold values, their results are not directly comparable with those obtained for Tasmania’s southern forest. However both these studies indicate that the non-timber values of the forest can be very significant.

REFERENCES

Adamowicz, W., J. Asafu-Adjaye, P.C. Boxall and W. Philips (1991), "Components of the Economic Value of Wildlife: an Alberta Case Study", *Canadian Field Naturalist* 105 (3), pp. 423-429.

Bowes, M.D. and J.V. Krutilla (1985), "Multiple Use Management of Public Forestlands", in A.V. Kneese and J.L. Sweeney (eds.), *Handbook of Natural Resource and Energy Economics* Vol. 2 (Amsterdam: Elsevier Science Publishers), pp. 531-569.

Bowes, M.D. and J.V. Krutilla (1989), *Multiple-Use Management: the Economics of Public Forestlands* (Washington D.C.: Resource for the Future), pp. xxiii + 357.

Calish, S., R.D. Fight and D.E. Teeguarden (1978), "How Do Non-timber Values Affect Douglas Fir Rotations?", *Journal of Forestry*, April, pp. 217-221.

Goodwin, A. (1999), "Generalized Yield Curves for single-aged Tasmanian Eucalypt Forest", Forestry Tasmania, pers. comm.

Hartley, S. (1995) "How Often Should Native Forests Be Logged? A Case Study on the Eden Management Area", *Economics and Labour Relations Review*, Vol. 62(2), pp. 196-215.

Hartman, R. (1976), "The Harvesting Decision when a Standing Forest Has Value", *Economic Inquiry* Vol. 14, pp. 52-58.

O'Shaughnessy, P.J. and D.A. Jayasuriya (1991), "Managing the Ash Type Forests for Water Production in Victoria" in *Forest Management in Australia* , F.H. Kinnel, E.R. Hopkins and J.E.D. Fox (eds.), Surrey Beatty & Sons.

Strang, W.J. (1983), "On the Optimal Forest Harvesting Decision", *Economic Inquiry,* Vol. 12, pp. 576-583.

Swallow, S.K., P.J. Parks and D.N. Wear (1990), "Policy Relevant Non-convexities in the Production of Multiple Forest Benefits", *Journal of Environmental Economics and Management*, Vol. 19, pp. 264-280.

Swallow, S.K., P. Talukdar and D.N. Wear (1997), "Spatial and Temporal Specialization in Forest Ecosystem Management Under Sole Ownership", *American Journal of Agricultural Economics*, Vol. 79, pp. 311-326.

Wills, I. (1997), *Economics and the Environment: a signalling and incentives approach* (Allen and Unwin).